

Aridity changes and its association with drought severity in Botswana

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Abstract

Global warming is likely to increase climatic variability especially in semi arid areas. The variability is expected to be registered through changes in rainfall patterns and temperature trends, thus through changes in aridity and drought severities. This makes it necessary to periodically monitor these climatic variables by examining trends in aridity and their association with drought severity. This study investigated trends in aridity using Mann-Kendall (MK) trend analysis and their association with drought severity using aridity indices (AI) and standardized precipitation evaporation indices (SPEI). This was achieved by using climatic information observed from 1960-2014 at 14 synoptic stations across Botswana. Results from seasonal aridity revealed that there was marginally increased aridity in 71% of the stations at the end of the summer rainfall (wet period) and in 64% of the stations at the end of the dry winter period. Marginally increasing trends for annual aridity was also observed in 64% of the stations at the end of December. Interestingly the trends in both seasonal and annual aridity were generally not found to be statistically significant except at Kasane. However, significant positive correlations between AI and SPEI were found except at Maun. The study concludes that though the association between drought severity and aridity index are significant albeit with insignificant changes in aridity indices, the drought severities in Botswana could be from short term droughts.

Key words: Aridity index, climate variability, correlation, global warming, Mann-Kendall, standardized precipitation evaporation index

Résumé

Le réchauffement climatique est susceptible d'amplifier la variabilité climatique, en particulier dans les zones semi-arides. La variabilité climatique peut être mesurée à travers les changements dans les modèles de précipitations et les tendances dans les températures, donc par les changements dans l'ampleur de l'aridité et de la sécheresse. Ceci conduit à la nécessité de suivre périodiquement ces variables climatiques, en examinant les tendances dans l'aridité et leur relation avec la sévérité de la sécheresse. La présente étude a examiné les tendances dans l'aridité à travers l'analyse des tendances de Mann-Kendall (MK) et

leur association avec l'ampleur de la sécheresse en utilisant les indices d'aridité (AI) et les indices standardisés d'évaporation des précipitations (SPEI). Ceci a été possible avec l'utilisation des données climatiques de 1960 à 2014 dans 14 stations synoptiques au Botswana. Les résultats de l'aridité saisonnière ont révélé une légère augmentation de l'aridité dans 71% des stations à la fin des pluies estivales (période humide) et dans 64% des stations à la fin de la période sèche d'hiver. Des tendances marginales à la hausse ont également été observées pour l'aridité annuelle dans 64% des stations à la fin du mois de décembre. Curieusement, les tendances de l'aridité saisonnière et annuelle généralement n'ont pas été significatives sauf à Kasane. Toutefois, des corrélations positives significatives entre IA et SPEI ont été observées sauf à Maun. On conclut que bien que l'association entre l'ampleur de la sécheresse et l'indice d'aridité soit significative même si les indices d'aridité ne changent pas de manière significative, l'ampleur de la sécheresse au Botswana pourrait bien provenir de la sécheresse à court terme.

Mots-clés: indice d'aridité, variabilité climatique, corrélation, réchauffement climatique, Mann-Kendall, indice standardisé d'évaporation des précipitations

Introduction

Aridity is a common phenomenon in the subtropics where anticyclone weather patterns are frequent and likely to have direct influence on the evaporation rates from surface reservoirs and other economic activities (Galarneau Jr *et al.*, 2008; Some'e *et al.*, 2013). On the other hand droughts are usually associated with the dryness conditions in a region due to climate anomalies such as decreased rainfall, increased temperature and evapotranspiration. Although aridity and droughts are in many ways associated, the main difference between them is in their scale in the sense that aridity arises from long term persistent dry conditions (Maliva and Missimer, 2012). In other words aridity could be referred to as an extreme manifestation of droughts.

Climate variability being closely related to the warming of the earth, is likely to cause frequent droughts and even make semi-arid regions arid or hyper arid (Zhang *et al.*, 2009; Some'e *et al.*, 2013; Byakatonda *et al.*, 2016). As per the recent Intergovernmental Panel on Climate Change (IPCC) projections, earth is likely to witness an increased warmer condition by 1- 2 °C in the near future which may even end up by 4 - 6 °C towards the end of the century (Pachauri and Reisinger, 2008; Kenabatho *et al.*, 2012). However, the climatic impacts may be felt at varying degrees depending on region and adaptation capability (Some'e *et al.*, 2013; Rahman and Lateh, 2015). These impacts are expected to be more severe in arid and semi arid areas making any meaningful economic activities such as crop production and livestock rearing unfeasible (Zhang *et al.*, 2009; Yu *et al.*, 2014). Botswana, one of the water scarce countries in the sub-Saharan Africa, is located below 20 °S of latitude, and is categorized as semi arid/arid based on its climate. It has been observed that the country which used to suffer from droughts once in 10 years in the '70s is slowly experiencing droughts roughly once in 5 years (20% of the time) in the recent past (Byakatonda *et al.*, 2016). Rainfall in Botswana is erratic and highly variable ranging from 600 mm in the northeast to 250 mm in the southwest. Further to this, it has been reported that temperature is the main

rainfall predictor and has been responsible for not only the decrease in rainfall but also in the inter-annual variability of rainfall (Parida and Moalafhi, 2008; Kenabatho *et al.*, 2012). For these foregoing situations, it has become imperative to understand not only the aridity trends due to the ongoing climatic variability but also to determine the association between the aridity and droughts severity in the study area.

Methodology

To understand the trend in aridity and the association between aridity and drought severity in Botswana, long term climate data (rainfall, minimum and maximum temperature) from 1960-2014 observed at 14 synoptic stations spread across the country were chosen and analyzed to generate aridity and standardized precipitation evaporation index (SPEI) series at two time scales viz: three and twelve months. The three months' time scale was chosen to get insight on seasonal drought/aridity changes while the twelve months' time scale was meant to reveal the long term annual changes. Steps used in the analyses are presented in the following sections.

Determination of aridity index (AI). Aridity is as a result of long term moisture deficiency conditions over a geographical location (Maliva and Missimer, 2012). The extent of dryness of a given climate at a particular location is quantifiable through aridity index (AI) which is a relationship between available precipitation and potential evapotranspiration. This study used the De Mortone formula which defines aridity in form of moisture deficit as applied in Maliva and Missimer (2012) and Zhang *et al.* (2009).

The aridity index (AI) is given by;

$$AI = \frac{12P_i}{10 + T_{i\text{mean}}} \dots\dots\dots (1)$$

Where P_i and $T_{i\text{mean}}$ are monthly rainfall and mean monthly temperature respectively.

Determination of drought severity. In the context of global warming, the SPEI was used to determine the magnitude and intensity of drought severity at time scales of three for seasonal and twelve months for long term changes. The SPEI was computed based on the following steps: i) Determination of reference evapotranspiration (ET_0), ii) aggregation of the climatic water balance ($P_i \% ET_0$), iii) fitting of the climatic water balance time series to an appropriate probability distribution function, and iv) Gaussian transformation of the water balance quantiles to obtain SPEI time series.

Trend analysis in the aridity index. The study applied the Mann-Kendall (MK) non parametric test statistic to detect the direction of any trend if it existed at all in the aridity indices at the defined time scales. This method was selected due to its ability to deal with outliers and non-uniformly distributed data (Gocic and Trajkovic, 2013; Tabari *et al.*, 2011). The Mk test is presented as;

$$S = \sum_{q=1}^{k-1} \sum_{r=1}^k \text{Sgn}(AI_r - AI_q) \dots\dots\dots (2)$$

Where ($r > q$)

The significance of the trend is then tested through the Z-statistic computed from;

$$Z_s = \begin{cases} \frac{S-1}{\sqrt{\text{Var}(S)}} & S > 0 \\ 0 & S = 0 \\ \frac{S+1}{\sqrt{\text{Var}(S)}} & S < 0 \end{cases} \dots\dots\dots (3)$$

The trend becomes statistically significant when the Z value computed in equation 3 is greater than a Z critical value obtained from standard normal tables. The effect of serial correlation on the trend was investigated through testing for significance of the lag 1 correlation. A negative (positive) trend in aridity signifies increasing (decreasing) dry conditions.

Association between aridity and drought severity. Bivariate statistical analysis was carried out to investigate the degree of association between aridity index and SPEI at the identified timescales. The AI time series were lagged for three and twelve months to correspond with the SPEI at a selected time scale. The Spearman correlation was applied to establish this association.

Results and discussion

Seasonal and annual trends of aridity time series. Using Eq. (2) and Eq. (3), results of trend statistics for seasonal AI-3 and annual AI-12 MK-Z are presented in Table 1. For the AI-3 at the end of March, 71% of the stations exhibited negative trends though none of them was statistically significant. At the end of the rainy season in March, results still indicated increasing aridity that may be attributed to decreasing rainfall amounts and rising temperature over the study area as have been reported by Parida and Moalafhi (2008) and Kenabatho *et al.* (2012).

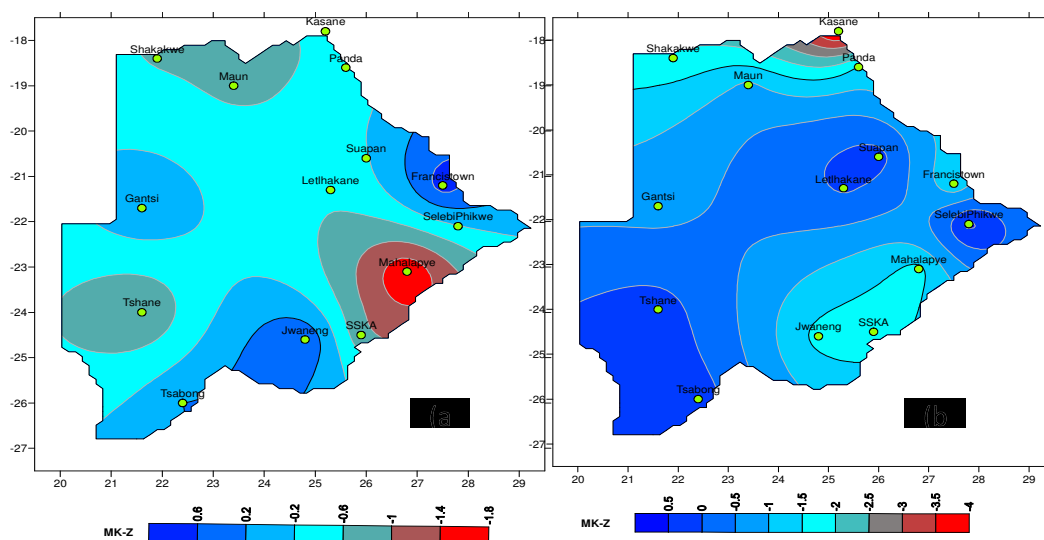
Further still at AI-3 trends determined at the end of the winter period in October, 64% of the stations presented negative trends in aridity. Kasane in the northeast is the only station that exhibited statistically significant negative trends. Positive trends were mainly in the south at Tshane and Tsabong though none of them was significant. Spatial distribution of these trends presented in Figure 1(b) indicates that the southern region which is already drier and borders the Kalahari Desert is experiencing positive trends in aridity. However, from this study, it was not possible to conclude if aridity is decreasing since none of the positive trends are statistically significant.

At twelve months' time scale (AI-12) aridity presents similar trends as those reported at the end of the winter period in Figure 1 (b). These results overall show that Botswana is still prone to increasing aridity with more than 60% of the locations experiencing increasing

Table 1. MK-Z trend test for aridity index and correlations between AI and SPEI

SN	Station name	MK Z Statistic			AI-SPEI Correlation	
		AI-3- March	AI-3- Oct	AI-12- Dec	3-Months	12-Months
1	Francistown	0.79	-1.41	1.4	0.516	0.952
2	Gantsi	0.15	-0.69	0.21	0.489	0.963
3	Jwaneng	0.58	-1.66	0.49	0.452	0.955
4	Kasane	-0.54	*-4.18	*-3.67	0.117	0.209
5	Letlhakane	-0.55	0.07	-0.29	0.490	0.933
6	Mahalapye	-1.76	-1.65	-1.47	0.545	0.969
7	Maun	-0.68	-0.89	-1.54	0.019	0.076
8	Panda	-0.5	-1.45	-1.4	0.358	0.635
9	SelebiPhikwe	-0.22	0.66	-0.55	0.531	0.848
10	Shakakwe	-0.63	-1.89	-0.85	0.399	0.957
11	SSKA	-0.88	-1.63	-0.51	0.589	0.979
12	Suapan	-0.23	0.19	0.23	0.520	0.945
13	Tsabong	0.2	0.25	0.69	0.599	0.943
14	Tshane	-1.04	0.21	-0.61	0.557	0.964

*Statistically significant trend at 95% confidence level

**Figure 1. Spatial distribution of MK Z statistic for aridity trends at three months' time scale (a) March and (b) October**

aridity over the study period in seasonal and annual trends. The increase in aridity poses future challenges to livestock and crop management.

Relationship between aridity and drought severity. Results from the Spearman correlation in Table 1 show positive correlations between aridity index and SPEI at all the 14 synoptic stations for the three and twelve months' time scales. All the correlations at these two time scales were significant except at Maun which reported a near zero correlation. Higher correlations were experienced at twelve months' time scale as compared to three months. This could be attributed to the more frequent alternations between wet and dry episodes of SPEI at lower time scales. Thus SPEIs become more pronounced at longer time scales generating into aridity (Lorenzo-Lacruz *et al.*, 2010; Byakatonda *et al.*, 2016). At three months' time scale, the highest correlation was recorded at Tsabong with a value

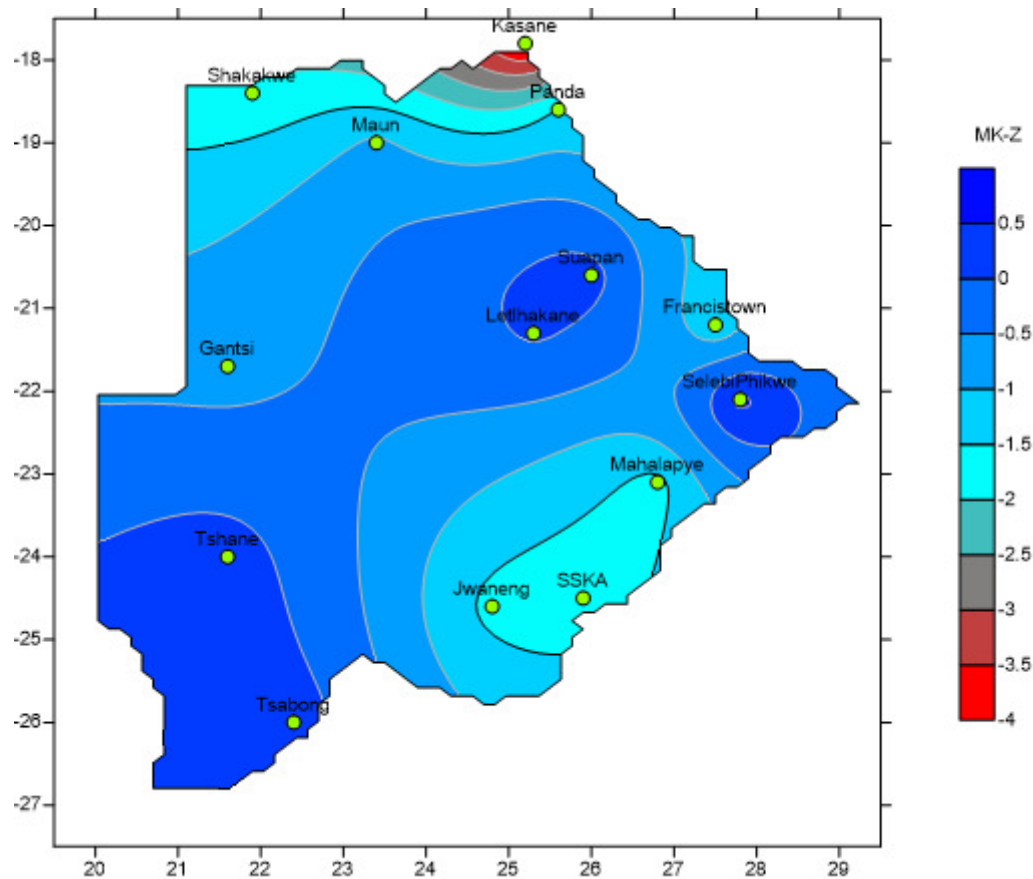


Figure 2. Spatial distribution of MK Z statistic for aridity trends at twelve months' time scale for December

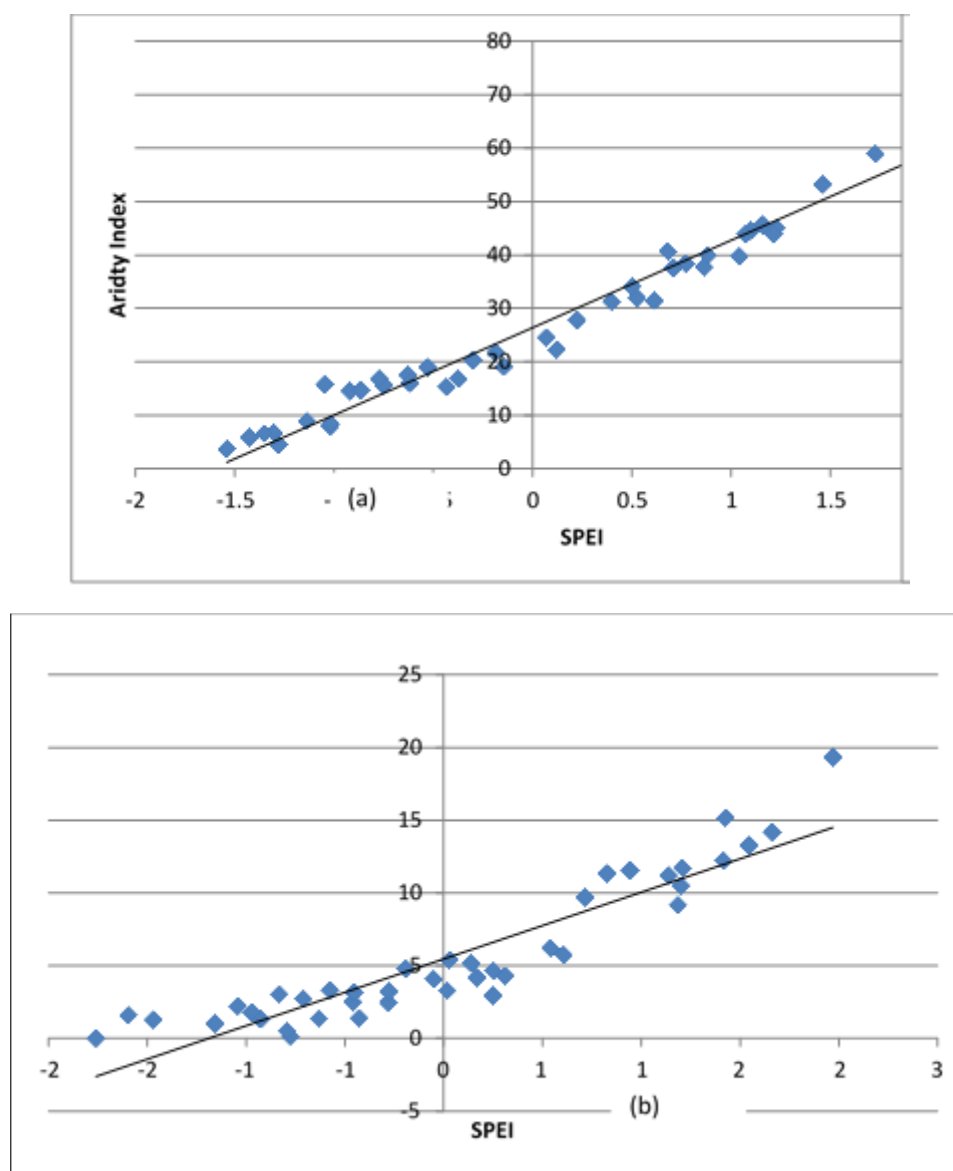


Figure 3. Regression plots at Mahalapye for three months' time scale (a) March and (b) October

of 0.60, whereas at twelve months highest correlation coefficient of 0.97 was recorded at Mahalapye. Typical plots of SPEI vs. aridity index at three months' time scale for the end of the wet period (March) and end of dry period (October) showing the fit are presented in Figure 3(a) and 3(b).

Conclusion

The following conclusions are drawn from the results of the study: .

1. Botswana is prone to aridity with 71% of the stations in summer and 64% in winter and annual scales experiencing increased aridity even though trends at most of them are not statistically significant except at Kasane. This could imply that Botswana is not possibly affected by long term droughts.
2. There exists a strong positive association between aridity and drought severity. This association can aid better drought management particularly in Botswana where majority of farmers practice rain-fed agriculture.

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